PARTICLE PHYSICS WORKSHEET

PHYSICS WITH CYRUS

Cyrus Ishaq

ISL, BLL, BCCG, LGS, Roots IVY P5

+923008471504

Q1 a) The results of the α-particle scattering experiment led to the development of the nuclear model for the atom.

State the results that suggested that most of the mass of the atom is concentrated in a very small region and most of the atom is empty space.

....

....

....

.... [2]

(b) State the composition of γ-radiation.

.... [1]

(c) Table 7.1 lists the names of three particles and possible classifications for them.

Table 7.1

particle name	classification		
	baryon	hadron	lepton
neutrino			
neutron			
positron			

Complete Table 7.1 by placing ticks (✓) in the boxes to indicate the classifications that apply to each particle. [2]

(d) The discovery of a particle with an unusual charge was an important step in the development of the theory of quarks. The particle is a hadron with a mass of 2.19×10^{-27} kg and a charge of $+2e$, where e is the elementary charge.

(i) Calculate the mass, in u, of the particle. Give your answer to three significant figures.

mass = ... u [1]

(ii) Determine a possible quark composition of a hadron with a charge of $+2e$. Explain your reasoning.

[2]

[Total: 8]

Q2 **(a)** In the following list, underline **all** the particles that are **not** fundamental.

antineutrino   baryon   nucleon   positron   [1]

(b) A nucleus of thorium-230 ($^{230}_{90}Th$) decays in stages, by emitting α-particles and β^- particles, to form a nucleus of lead-206 ($^{206}_{82}Pb$).

Determine the total number of α-particles and the total number of β^- particles that are emitted during the sequence of decays that form the nucleus of lead-206 from the nucleus of thorium-230.

number of α-particles = ...

number of β^- particles = ...

[2]

(c) A meson has a charge of –1*e*, where *e* is the elementary charge. The quark composition of the meson includes a charm antiquark.

State and explain a possible flavour (type) of the other quark in the meson.

....

.... [2]

[Total: 5]

Q3 **(a)** The nuclide $^{23}_{12}Mg$ is an isotope of magnesium that undergoes β^+ decay to form a new nuclide X according to the equation

$$^{23}_{12}Mg \rightarrow \, ^{\dots\dots}_{\dots\dots}X + \, ^{\dots\dots}_{\dots\dots}\beta^+ + \, ^{0}_{0}\nu.$$

Four numbers are missing from the equation.

(i) For the nuclide $^{23}_{12}Mg$, state what is represented by the numbers 23 and 12.

23 represents: ....

12 represents: ....
[2]

(ii) Complete the equation by inserting the missing numbers. [2]

(iii) State the name of the group (class) of fundamental particles to which the positron and neutrino belong.

.... [1]

(b) A radioactive source emits particles from its nuclei when it decays.
Fig. 8.1 shows, for the source, the variation with kinetic energy of the number of particles emitted.

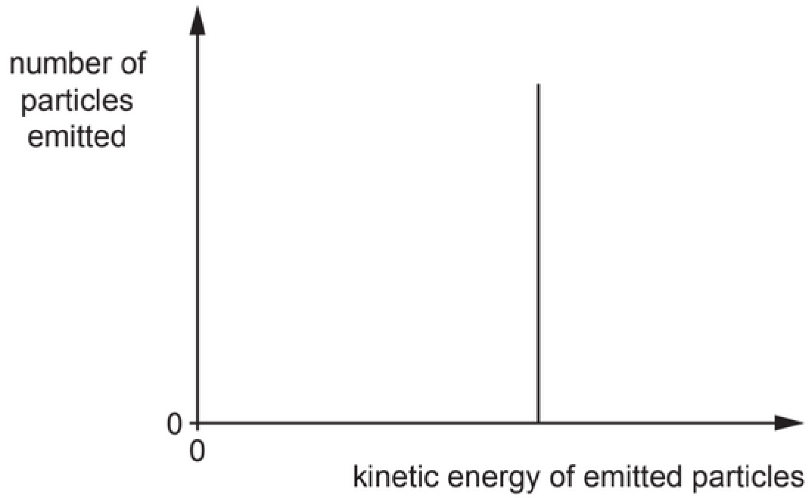

Fig. 8.1

State how Fig. 8.1 shows that these nuclei do **not** undergo beta-decay.

....

.... [1]

[Total: 6]

Q4 An isolated stationary nucleus X decays by emitting an α-particle to form a nucleus Y.

Nucleus Y and nucleus Z are isotopes of the same element.

(a) By comparing the number of protons in each nucleus, state and explain whether the charge of nucleus Y is less than, greater than or the same as the charge of:

(i) nucleus Z

....

.... [1]

(ii) nucleus X.

....

....

.... [2]

(b) Use the principle of conservation of momentum to explain why nucleus Y cannot be stationary immediately after the decay of nucleus X.

....

....

....

.... [2]

[Total: 5]

Q5 **(a)** Nucleus P and nucleus Q are isotopes of the same element.

Nucleus Q is unstable and emits a β^- particle to form nucleus R.

(i) For nuclei P and Q, compare:

- the number of protons

....

- the number of neutrons.

....

[2]

(ii) When nucleus Q decays to form nucleus R, the quark composition of a nucleon changes.

State the change to the quark composition of the nucleon.

.... [1]

(iii) State the name of another particle that must be emitted from nucleus Q in addition to the β^- particle.

.... [1]

(b) A hadron consists of two charm quarks and one bottom quark.

Determine, in terms of the elementary charge *e*, the charge of the hadron.

charge = ... *e* [2]

[Total: 6]

Q6 **(a)** Table 7.1 shows incomplete data for three flavours (types) of quark. The elementary charge is *e*.

Table 7.1

flavour	quark		antiquark	
	symbol	charge / *e*	symbol	charge / *e*
up	u	$+\frac{2}{3}$	$\bar{u}$	
down	d		$\bar{d}$	
charm	c		$\bar{c}$	

Complete Table 7.1 by inserting the missing charges. [2]

(b) Using the symbols given in Table 7.1, state a possible quark combination for the following hadrons:

(i) a neutral baryon

.... [1]

(ii) a meson with a charge of +*e*.

.... [1]

(c) Quarks are fundamental particles.

Electrons are in another group (class) of fundamental particle.

(i) State the name of this group.

.... [1]

(ii) State the name of another particle in this group.

.... [1]

[Total: 6]

Q7 **a)** A lepton is an example of a fundamental particle.

State what is meant by fundamental particle.

....

.... [1]

(b) A lambda particle Λ^0 is a hadron that consists of an up (u) quark, a down (d) quark and a strange (s) quark.

Show that the charge on the Λ^0 particle is zero.

[2]

(c) The Λ^0 particle is unstable. It can decay into a neutron (n) and a pion (π^0) as shown by

$$\Lambda^0 \longrightarrow n + \pi^0.$$

The π^0 particle consists of an up quark and an up antiquark.

(i) Compare the properties of an up quark and an up antiquark.

....

....

.... [2]

(ii) Explain why the neutron is classed as a baryon and the π^0 particle is classed as a meson.

....

....

.... [2]

[Total: 7]

Q8 **(a)** The nuclide $^{14}_{6}C$ (carbon-14) is unstable and undergoes β^- decay, emitting a high-energy electron and an antineutrino to form a new nuclide X. The equation for this decay is shown.

$$^{14}_{6}C \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}X + \,^{\cdots\cdots}_{\cdots\cdots}e^- + \,^{0}_{0}\overline{\nu}$$

Complete the equation. [2]

(b) **(i)** State the equation for β^- decay in terms of the fundamental particles involved.

[1]

(ii) Use your equation from **(b)(i)** to show how charge is conserved in β^- decay.

[1]

(c) Neutrinos were first proposed to exist more than 20 years before they were directly detected, in order to explain a particular experimental observation about β-decay.

(i) State an observation about β-decay that is explained by the existence of neutrinos.

....

....

.... [1]

(ii) Suggest how the existence of neutrinos explains the observation in **(c)(i)**.

....

....

.... [1]

[Total: 6]

Q9

(a) Describe the structure of an **atom** of uranium-238, $^{238}_{92}U$.

....

....

.... [2]

(b) The decay of uranium-238 is shown by the equation

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + X.$$

For nucleus X, calculate the ratio, in $C\,kg^{-1}$, of

$$\frac{\text{charge}}{\text{mass}}.$$

ratio = ... $C\,kg^{-1}$ [3]

(c) Two particles P and Q each consist of three quarks. These quarks are up (u) or down (d) quarks.

Particle P has no overall charge.

Particle Q has an overall charge of $+2e$, where e is the elementary charge.

State the quark composition of:

(i) particle P

.... [1]

(ii) particle Q.

.... [1]

[Total: 7]

Q10 **(a)** An unstable nucleus ${}^{A}_{Z}X$ decays by emitting a β^- particle.

(i) Determine quantitatively the changes, if any, in *A* and *Z* when X decays.

change in *A* = ...

change in *Z* = ...
[2]

(ii) In addition to the β^- particle, another lepton is emitted during the decay.

State the name of the other lepton that is emitted.

.... [1]

(b) A particle P is composed of an up quark (u) and a down antiquark ($\overline{d}$).

(i) Calculate the charge *q* of particle P in terms of *e*, where *e* is the elementary charge.

Show your working.

q = ... *e* [2]

(ii) Particle P belongs to **two** classes (groups) of particles.

State the names of these two classes.

1 ....

2 ....
[2]

[Total: 7]

Q11 **a)** A nucleus of caesium-137 ($^{137}_{55}Cs$) decays by emitting a β^- particle to produce a nucleus of an element X and an antineutrino. The decay is represented by

$$^{137}_{55}Cs \rightarrow {}^{Q}_{S}X + {}^{P}_{R}\beta^- + {}^{0}_{0}\bar{\nu}.$$

(i) State the number represented by each of the following letters.

P ....

Q ....

R ....

S ....

[2]

(ii) State the name of the class (group) of particles that includes the β^- particle and the antineutrino.

.... [1]

(b) A particle Y has a quark composition of ddd where d represents a down quark.

A particle Z has a quark composition of $\bar{u}d$ where $\bar{u}$ represents an up antiquark.

(i) Show that the charges of particles Y and Z are equal.

[2]

(ii) State and explain which particle is a meson and which particle is a baryon.

meson: ....

....

baryon: ....

....

[2]

[Total: 7]

Q12 **a)** Fluorine-18 ($^{18}_{9}F$) is an isotope that decays to an isotope of oxygen (O) by the emission of a β^+ particle.

(i) Complete the nuclear equation for the decay, including all the particles involved.

$$^{18}_{9}F \rightarrow$$

[3]

(ii) A quark in the fluorine-18 nucleus changes flavour during the decay. State this change of flavour.

.... quark to .... quark. [1]

(b) A hadron has a charge of –2*e*, where *e* is the elementary charge.

(i) State and explain whether the hadron is a meson or a baryon.

....

....

.... [2]

(ii) State a possible quark composition for the hadron.

....

.... [1]

[Total: 7]

Q13 **(a)** A nucleus of sodium-22 ($^{22}_{11}Na$) decays by emitting a β^+ particle. A different nucleus is formed by the decay.

(i) State the name of another lepton that is produced by the decay.

.... [1]

(ii) Determine the nucleon number and the proton number of the nucleus that is formed by the decay.

nucleon number = ...

proton number = ...

[2]

(iii) The quark composition of a nucleon in the sodium-22 nucleus is changed during the decay.

Describe the change to the quark composition of the nucleon.

....

.... [1]

(b) A baryon consists of quarks that are the same flavour (type). The charge of the baryon is –2*e*, where *e* is the elementary charge.

(i) Calculate, in terms of *e*, the charge of each quark.

charge = ... *e* [1]

(ii) State a possible flavour (type) of the quarks.

.... [1]

[Total: 6]

Q14 **(a)** Nuclei X and Y are different isotopes of the same element.

Nucleus X is unstable and emits a β^+ particle to form nucleus Z.

By comparing the number of protons in each nucleus, state and explain whether the charge of nucleus X is less than, the same as or greater than the charge of:

(i) nucleus Y

....

.... [1]

(ii) nucleus Z.

....

....

.... [2]

(b) Hadrons can be divided into two groups (classes), P and Q. Group P is baryons.

(i) State the name of group Q.

.... [1]

(ii) Describe, in general terms, the quark structure of hadrons that belong to group Q.

....

.... [1]

[Total: 5]

Q15 A stationary nucleus P of mass 243 u decays by emitting an α-particle of mass 4 u to form a different nucleus Q, as illustrated in Fig. 7.1.

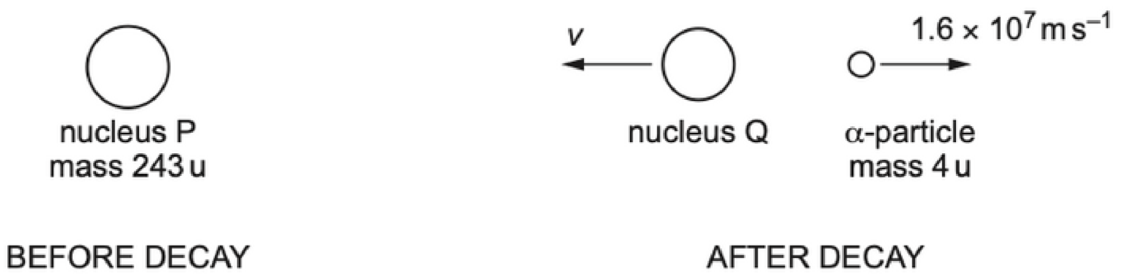

Fig. 7.1

The initial speed of the α-particle is $1.6 \times 10^7\,\text{m s}^{-1}$.

(a) Use the principle of conservation of momentum to explain why the initial velocities of nucleus Q and the α-particle must be in opposite directions.

....

....

....

.... [2]

(b) Determine the initial speed *v* of nucleus Q.

v = ... m s^{-1} [2]

(c) Calculate the initial kinetic energy, in MeV, of the α-particle.

kinetic energy = ... MeV [3]

(d) A graph of number of neutrons N against proton number Z is shown in Fig. 7.2.

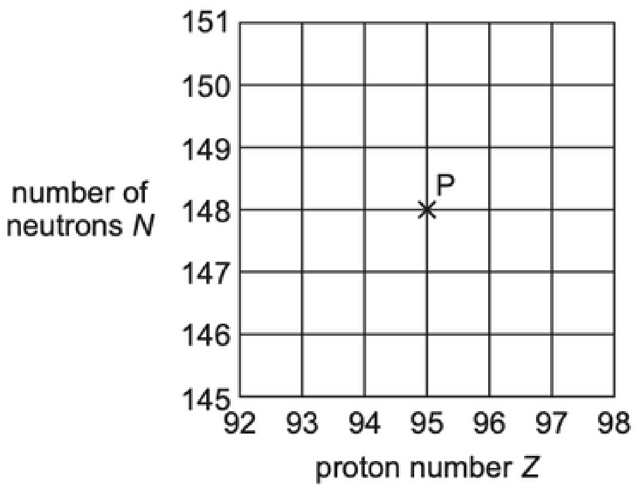

Fig. 7.2

The graph shows a cross that represents nucleus P.

A nucleus R has a nucleon number of 242 and is an isotope of nucleus P.

Nucleus R decays by emitting a β^- particle to form a different nucleus S.

(i) On Fig. 7.2, draw a cross to represent:

1. nucleus R (label this cross R)

2. nucleus S (label this cross S).

[2]

(ii) State the name of the other lepton, in addition to the β^- particle, that is emitted during the decay of nucleus R.

.... [1]

[Total: 10]

Q16 **(a)** Complete Table 6.1 to show the masses (in terms of the unified atomic mass unit u) and charges (in terms of the elementary charge *e*) of α, β^+ and β^- particles.

Table 6.1

	mass / u	charge / *e*
α-particle		
β^+ particle		
β^- particle		

[4]

(b) Carbon-14 is radioactive and decays by emission of β^- particles.

(i) Nuclei do not contain β^- particles.

Explain the origin of the β^- particle that is emitted from the nucleus during β^- decay.

....

....

.... [1]

(ii) State the change in the quark composition of a carbon-14 nucleus when it emits a β^- particle.

.... [1]

(iii) Suggest why the β^- particles are emitted with a range of different energies.

....

....

....

.... [2]

[Total: 8]

Q17 **(a)** One of the results of the α-particle scattering experiment is that a very small minority of the α-particles are scattered through angles greater than 90°.

State what may be inferred about the structure of the atom from this result.

....

....

....

.... [2]

(b) An α-particle is made up of other particles. One of these particles is a proton.

State and explain whether a proton is a fundamental particle.

....

.... [1]

(c) A radioactive source produces a beam of α-particles in a vacuum. The average current produced by the beam is 6.9×10^{-9} A.

Calculate the average number of α-particles passing a fixed point in the beam in a time of 1.0 minute.

number = ... [3]

Q18 **(a)** A proton in a nucleus decays to form a neutron and a β^+ particle.

(i) State the name of another lepton that is produced in the decay.

.... [1]

(ii) State the name of the interaction (force) that gives rise to this decay.

.... [1]

(iii) State which of the three particles (proton, neutron or β^+ particle) has the largest ratio of charge to mass.

.... [1]

(iv) Use the quark model to show that the charge on the proton is +*e*, where *e* is the elementary charge.

[2]

(v) The quark composition of the proton is changed during the decay.

Describe the change to the quark composition.

....

.... [1]

Q19 **(a)** State the quark composition of:

(i) a proton

.... [1]

(ii) a neutron

.... [1]

(iii) an alpha-particle.

....

.... [2]

(b) In the alpha-particle scattering experiment, alpha-particles were directed at a thin gold foil.

State what may be inferred from:

(i) the observation that most alpha-particles pass through the foil

.... [1]

(ii) the observation that some alpha-particles are scattered through angles greater than 90°.

....

....

.... [2]

Q20 **(a)** The results of the α-particle scattering experiment provide evidence for the structure of the atom.

Result 1: The vast majority of the α-particles pass straight through the metal foil or are deviated by small angles.

Result 2: A very small minority of α-particles is scattered through angles greater than 90°.

State what may be inferred (deduced) from:

(i) result 1

....

.... [1]

(ii) result 2.

....

....

.... [2]

(b) A radioactive decay sequence contains four nuclei, P, Q, R and S, as shown.

$$^{218}_{84}\text{P} \rightarrow {}^{214}_{82}\text{Q} \rightarrow {}^{214}_{83}\text{R} \rightarrow \text{S}$$

Nucleus S is an isotope of nucleus P.

(i) Determine the proton number and the nucleon number of nucleus S.

proton number = ...

nucleon number = ... [2]

(ii) The quark composition of a nucleon in Q changes as Q decays to form R.

Describe this change to the quark composition of the nucleon.

....

.... [1]

[Total: 6]

Q21 The β^- particle is emitted from the source with a kinetic energy of 3.4×10^{-16} J.

Calculate the speed at which the β^- particle is emitted.

speed = ... ms^{-1} [2]

(c) The β^- particle is produced by the decay of a neutron.

(i) Complete the equation below to represent the decay of the neutron.

$${}^{1}_{0}n \rightarrow {}^{0}_{-1}\beta^- + {}^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots\cdots + {}^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots\cdots$$

[2]

(ii) State the name of the group (class) of particles that includes:

1. neutrons

....

2. β^- particles.

....

[2]

Q22 A nucleus of plutonium-238 ($^{238}_{94}Pu$) decays by emitting an α-particle to produce a new nucleus X and 5.6 MeV of energy. The decay is represented by

$$^{238}_{94}\text{Pu} \rightarrow \text{X} + \alpha + 5.6\,\text{MeV}.$$

(a) Determine the number of protons and the number of neutrons in nucleus X.

number of protons = ...

number of neutrons = ...
[2]

(b) Calculate the number of plutonium-238 nuclei that must decay in a time of 1.0 s to produce a power of 0.15 W.

number = ... [2]

[Total: 4]

Q23 **(a)** The decay of a nucleus $^{35}_{18}Ar$ by β^+ emission is represented by

$$^{35}_{18}\text{Ar} \rightarrow \text{X} + \beta^+ + \text{Y}.$$

A nucleus X and two particles, β^+ and Y, are produced by the decay.

State:

(i) the proton number and the nucleon number of nucleus X

proton number = ...

nucleon number = ...
[1]

(ii) the name of the particle represented by the symbol Y.

.... [1]

(b) A hadron consists of two down quarks and one strange quark.

Determine, in terms of the elementary charge e, the charge of this hadron.

charge = ... [2]

[Total: 4]

Q24 A stationary nucleus of a radioactive isotope X decays by emitting an α-particle to produce a nucleus of neptunium-237 and 5.5 MeV of energy. The decay is represented by

$$X \rightarrow {}^{237}_{93}Np + \alpha + 5.5\,MeV.$$

(a) Calculate the number of protons and the number of neutrons in a nucleus of X.

number of protons = ...

number of neutrons = ...
[2]

(b) Explain why the energy transferred to the α-particle as kinetic energy is less than the 5.5 MeV of energy released in the decay process.

....

.... [1]

(c) A sample of X is used to produce a beam of α-particles in a vacuum. The number of α-particles passing a fixed point in the beam in a time of 30 s is 6.9×10^{11}.

(i) Calculate the average current produced by the beam of α-particles.

current = ... A [2]

(ii) Determine the total power, in W, that is produced by the decay of 6.9×10^{11} nuclei of X in a time of 30 s.

power = ... W [2]

[Total: 7]

Q25 **(a)** One of the results of the α-particle scattering experiment is that a very small minority of the α-particles are scattered through angles greater than 90°.

State what may be inferred about the structure of the atom from this result.

....

....

....

....[2]

(b) A hadron has an overall charge of $+e$, where e is the elementary charge. The hadron contains three quarks. One of the quarks is a strange (s) quark.

(i) State the charge, in terms of e, of the strange (s) quark.

charge = ... [1]

(ii) The other two quarks in the hadron have the same charge as each other.

By considering charge, determine a possible type (flavour) of the other two quarks. Explain your working.

....

....[2]

[Total: 5]

Q26 (a) State **one** difference between a hadron and a lepton.

....

.... [1]

(b) A proton within a nucleus decays to form a neutron and two other particles. A partial equation to represent this decay is

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{.....}_{.....}...... + {}^{.....}_{.....}......$$

(i) Complete the equation. [2]

(ii) State the name of the interaction or force that gives rise to this decay.

.... [1]

(iii) State three quantities that are conserved in the decay.

1. ....

2. ....

3. ....

[3]

(c) Use the quark composition of a proton to show that it has a charge of $+e$, where e is the elementary charge.

Explain your working.

[3]

[Total: 10]

Q27 **(a)** State **one** difference between a hadron and a lepton.

....

....[1]

(b) **(i)** State the quark composition of a proton and of a neutron.

proton: ....

neutron: ....

[2]

(ii) Use your answer in **(i)** to determine the quark composition of an α-particle.

quark composition: ....[1]

(c) The results of the α-particle scattering experiment provide evidence for the structure of the atom.

result 1: The vast majority of α-particles pass straight through the metal foil or are deviated by small angles.

result 2: A very small minority of α-particles are scattered through angles greater than 90°.

State what may be inferred from

(i) result 1,

....

....[1]

(ii) result 2.

....

....

....

....[2]

[Total: 7]

Q28 **(a)** State the name of the class (group) to which each of the following belongs:

electron ....

neutron ....

neutrino ....

proton ....

[2]

(b) A proton may decay into a neutron together with two other particles.

(i) Complete the following to give an equation that represents this proton decay.

$$^{1}_{1}p \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}n + {}^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots + {}^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots$$

[2]

(ii) Write an equation for this decay in terms of quark composition.

[1]

(iii) State the name of the force responsible for this decay.

....[1]

[Total: 6]

Q29 A neutron within a nucleus decays to produce a proton, a β^- particle and an (electron) antineutrino.

$$n \longrightarrow p + \beta^- + \bar{\nu}$$

(a) Use the quark composition of the neutron to show that the neutron has no charge.

[3]

(b) Complete Fig. 8.1 by giving appropriate values of the charge and the mass of the proton, the β^- particle and the (electron) antineutrino.

	proton	β^- particle	antineutrino
charge			
mass			

Fig. 8.1

[2]

[Total: 5]

Q30 A sample of a radioactive isotope emits a beam of β^- radiation.

(a) State the change, if any, to the number of neutrons in a nucleus of the sample that emits a β^- particle.

....[1]

(b) The number of β^- particles passing a fixed point in the beam in a time of 2.0 minutes is 9.8×10^{10}.

Calculate the current, in pA, produced by the beam of β^- particles.

current = ... pA [3]

(c) Suggest why the β^- particles are emitted with a range of kinetic energies.

....

....

....

....[2]

[Total: 6]

Q4

…)	Y and Z have equal numbers of protons and (so) they have the same charge	B1
8(a)(ii)	Y has (two) fewer protons (than X)	M1
	(so) Y has less charge (than X)	A1
8(b)	(total) momentum before decay is zero **or** X has zero / no momentum	B1
	(total momentum after decay must be zero so) Y must have equal (and opposite) momentum to α-particle (so cannot be stationary / must have speed/velocity)	B1

Q5

	number of protons: equal/same	B1
	number of neutrons: unequal/different	B1
8(a)(ii)	down (quark) changes to up (quark) **or** up down down (quarks) change to up up down (quarks)	B1
8(a)(iii)	(electron) antineutrino	B1
8(b)	charm (quark charge) is (+)2/3(e) **or** 2 charm (quark charges) is (+)4/3(e) **or** bottom (quark charge) is –1/3(e)	C1
	charge = +2/3(e) + 2/3(e) –1/3(e) = (+)1(e)	A1

Q6

	down charge = –1/3(e) **and** charm charge = (+)2/3(e)	B1
	all antiquarks have opposite sign and same (non-zero) magnitude of charge as the corresponding quarks	B1
7(b)(i)	udd **or** cdd	B1
7(b)(ii)	$u\bar{d}$ **or** $c\bar{d}$	B1
7(c)(i)	lepton(s)	B1
7(c)(ii)	positron / neutrino / antineutrino	B1

Q7

	particle with no internal structure / particle which cannot be broken down into anything smaller	A1
	charges: $u = (+)\frac{2}{3}(e)$ **or** $d = -\frac{1}{3}(e)$ **or** $s = -\frac{1}{3}(e)$	C1
	$(+)\frac{2}{3}(e) - \frac{1}{3}(e) - \frac{1}{3}(e) = 0(e)$	A1
6(c)(i)	• same/equal mass • same/equal (magnitude of) charge • both fundamental (particles) • opposite (sign of) charge • one is matter and the other is antimatter *Any two points, 1 mark each.*	B2
6(c)(ii)	neutron/baryon consists of three quarks	B1
	pion/meson consists of one quark and one antiquark	B1

Q8

	$^{14}_{7}X$	B1
	$^{0}_{-1}e^{-}$	B1
6(b)(i)	$d \rightarrow u + e^{-} + \bar{\nu}$ **or** $udd \rightarrow uud + e^{-} + \bar{\nu}$	B1
6(b)(ii)	–1 / 3 (*e*) = + 2 / 3 (*e*) – 1(*e*) (+ 0) **or** 2 / 3 (*e*) – 1 / 3 (*e*) – 1 / 3 (*e*) = 2 / 3 (*e*) + 2 / 3 (*e*) – 1 / 3 (*e*) – 1 (*e*) (+ 0)	B1
6(c)(i)	electrons / β-particles (emitted from the nucleus) have a (continuous) range of / different (kinetic) energies	B1
6(c)(ii)	the (emitted) neutrinos take varying amounts of the (same total) energy (released in the decay)	B1

Q9

	92 protons and 146 neutrons (in nucleus)	B1
	92 (orbital) electrons	B1
7(b)	charge = 2*e* (= $2 \times 1.60 \times 10^{-19}$ C)	C1
	mass = 4u (= $4 \times 1.66 \times 10^{-27}$ kg)	C1
	ratio = $(2 \times 1.60 \times 10^{-19}) / (4 \times 1.66 \times 10^{-27})$ = 4.8×10^{7} C kg^{-1}	A1
7(c)(i)	up down down / udd	B1
7(c)(ii)	up up up / uuu	B1

Q10

	change in *A* = 0	A1
	change in *Z* = (+)1	A1
7(a)(ii)	(electron) <u>anti</u>neutrino	B1
7(b)(i)	up / u (charge) = $(+)\frac{2}{3}e$ **or** antidown / $\bar{d}$ = $(+)\frac{1}{3}e$ **or** $(q) = \frac{2}{3}e + \frac{1}{3}e$	M1
	$q = (+)1e$	A1
7(b)(ii)	hadron(s)	B1
	meson(s)	B1

Q11

	P = 0 **and** Q = 137	A1
	R = –1 **and** S = 56	A1
7(a)(ii)	lepton(s)	B1
7(b)(i)	(charge of ddd / Y =) $-\frac{1}{3}(e)\ -\frac{1}{3}(e)\ -\frac{1}{3}(e) = -1(e)$	B1
	(charge of $\bar{u}$d / Z =) $-\frac{1}{3}(e)\ -\frac{2}{3}(e) = -1(e)$	B1
7(b)(ii)	meson: Z / $\bar{u}$ d because consists of a quark and an antiquark	B1
	baryon: Y / ddd because consists of three quarks	B1

Q12

	${}^{18}_{9}F \rightarrow {}^{18}_{8}O + {}^{0}_{(+)1}\beta^{(+)} + {}^{(0)}_{(0)}\nu_{(e)}$ ν **or** neutrino (B1) ${}^{0}_{(+)1}\beta^{(+)}$ (B1) ${}^{18}_{8}O$ (B1)	**B3**
7(a)(ii)	up quark to down quark	**B1**
7(b)(i)	must be three (anti)quarks as largest (negative) quark charge is (–)2/3 (*e*) **or** mesons can only have a charge of 0 or ±1(*e*)	**M1**
	(so hadron is) a baryon	**A1**
7(b)(ii)	any combination of three from: antiup (quark) / up antiquark and/or anticharm (quark) / charm antiquark and/or antitop (quark) / top antiquark	**B1**

Q13

	(electron) neutrino	**B1**
7(a)(ii)	nucleon number = 22	**A1**
	proton number = 10	**A1**
7(a)(iii)	up up down changes to up down down or up changes to down	**B1**
7(b)(i)	charge = $-\frac{2}{3}e$	**A1**
7(b)(ii)	antiup / anticharm / antitop	**B1**

Q14

7(a)(i)	X has same number of protons as Y (and so) charge of X is the same as the charge of Y	**B1**
7(a)(ii)	X has (one) more proton (than Z)	**M1**
	(so) X has greater charge (than Z)	**A1**
7(b)(i)	meson(s)	**B1**
7(b)(ii)	one quark and one antiquark	**B1**

Q15

	(total) momentum before (decay) is zero **or** P has zero momentum	**B1**
	(total momentum after decay must be zero so) α-particle and Q have momenta in opposite directions (and therefore velocities are in opposite directions)	**B1**
7(b)	$p = 239\text{ (u)} \times v$ **or** $4\text{ (u)} \times 1.6 \times 10^7$	**C1**
	$239\text{ (u)} \times v = 4\text{ (u)} \times 1.6 \times 10^7$ $v = 2.7 \times 10^5\text{ m s}^{-1}$	**A1**
7(c)	$E_{(K)} = \frac{1}{2}mv^2$	**C1**
	$= \frac{1}{2} \times 4 \times 1.66 \times 10^{-27} \times (1.6 \times 10^7)^2$	**C1**
	$= 8.5 \times 10^{-13}$ (J) $= 8.5 \times 10^{-13} / 1.60 \times 10^{-13}$ (MeV) $= 5.3$ MeV	**A1**

Q16

	α-particle mass given as 4u	B1
	α-particle charge given as (+)2e	B1
	both β-particles mass given as 0.0005 u	B1
	β^+ charge given as (+)e and β^- charge given as $-e$ (Completed table: <table><tr><td></td><td>mass / u</td><td>charge / e</td></tr><tr><td>α</td><td>4</td><td>(+)2</td></tr><tr><td>β⁺</td><td>0.0005</td><td>(+)1</td></tr><tr><td>β⁻</td><td>0.0005</td><td>–1</td></tr></table>)	B1
6(b)(i)	neutron decays into proton and an electron / β^- particle	B1
6(b)(ii)	down to up	B1
6(b)(iii)	(electron) antineutrino(s) emitted	B1
	energy (released in decay)/momentum shared between antineutrino and β^- particle	B1

Q17

	the nucleus is charged	B1
	the majority of the mass (of atom) is in the nucleus	B1
6(b)	made up of quarks (so) not a fundamental particle	B1
6(c)	(Q =) $6.9 \times 10^{-9} \times 60$	C1
	number $= (6.9 \times 10^{-9} \times 60) / (2 \times 1.60 \times 10^{-19})$	C1
	$= 1.3 \times 10^{12}$	A1

Q18

	(electron) neutrino	B1
6(a)(ii)	weak (nuclear force/interaction)	B1
6(a)(iii)	β^+ (particle)	B1
6(a)(iv)	(quark structure is) up up down **or** uud	B1
	$(2/3)e + (2/3)e - (1/3)e = (+)e$	B1
6(a)(v)	up up down changes to up down down **or** uud → udd **or** up changes to down **or** u → d	B1

Q19

	up up down	B1
6(a)(ii)	up down down	B1
6(a)(iii)	(alpha-particle is) 2 protons and 2 neutrons	C1
	6 up, 6 down	A1
6(b)(i)	most of an <u>atom</u> is empty space **or** the nucleus (volume) is (very) small <u>compared with the atom</u>	B1
6(b)(ii)	the nucleus is charged	B1
	the majority of the mass of atom is in the nucleus	B1

Q20	most of the atom is empty space *or* the nucleus (volume) is very small <u>compared to the atom</u>	**B1**
7(a)(ii)	the nucleus is charged	**B1**
	the mass is <u>concentrated</u> in nucleus / small region / small volume / small core *or* the <u>majority</u> of the mass is in nucleus / small region / small volume / small core	**B1**
7(b)(i)	proton number = 84	**A1**
	nucleon number = 214	**A1**
7(b)(ii)	up down down changes to up up down / udd $\rightarrow$ uud *or* down changes to up / d $\rightarrow$ u	**B1**

Q21	$E = \frac{1}{2}mv^2$	**C1**
	$3.4 \times 10^{-16} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$ $v = 2.7 \times 10^7\ \text{m s}^{-1}$	**A1**
7(c)(i)	$^{1}_{1}\text{p}$	**A1**
	$^{0}_{0}\bar{\nu}_{(e)}$	**A1**
7(c)(ii)	**1.** hadrons	**B1**
	2. leptons	**B1**

Q22	number of protons = 92	**A1**
	number of neutrons = 142	**A1**
7(b)	$5.6\ \text{MeV} = 5.6 \times 1.60 \times 10^{-19} \times 10^6$ $(= 8.96 \times 10^{-13}\ \text{J})$	**C1**
	number $= 0.15 / (5.6 \times 1.60 \times 10^{-13})$ $= 1.7 \times 10^{11}$	**A1**
	or	
	$0.15\ \text{W} = 0.15 / (1.60 \times 10^{-19} \times 10^6)$ $(= 9.38 \times 10^{11}\ \text{MeV s}^{-1})$	**(C1)**
	number $= 9.38 \times 10^{11} / 5.6$ $= 1.7 \times 10^{11}$	**(A1)**

Q23	proton number = 17 **and** nucleon number = 35	**A1**
7(a)(ii)	(electron) neutrino	**B1**
7(b)	d/down (quark charge) is $-\frac{1}{3}(e)$ **or** <u>two</u> d/down (quark charges) is $-\frac{2}{3}(e)$ **or** s/strange (quark charge) is $-\frac{1}{3}(e)$	**C1**
	charge $= -\frac{1}{3}(e) - \frac{1}{3}(e) - \frac{1}{3}(e)$ $= -1(e)$	**A1**

Q24

	number of protons = 95	A1
	number of neutrons = 146	A1
7(b)	Np/neptunium (nucleus) has kinetic energy **or** gamma/γ-radiation produced	B1
7(c)(i)	$I = NQ / t$	C1
	$I = (6.9 \times 10^{11} \times 2 \times 1.60 \times 10^{-19}) / 30$ $= 7.4 \times 10^{-9}$ A	A1
7(c)(ii)	$P = (6.9 \times 10^{11} \times 5.5 \times 10^{6} \times 1.60 \times 10^{-19}) / 30$	C1
	= 0.020 W	A1

Q25

	nucleus is charged	B1
	the mass is concentrated in (very small) nucleus **or** the majority of the mass is in (very small) nucleus	B1
7(b)(i)	$-(1 / 3)e$	B1
7(b)(ii)	$2q - (1 / 3)e = e$ so $q = (2 / 3)e$	M1
	up / u (quarks) (*allow charm or top quarks*)	A1

Q26 **(a)** hadron not a fundamental particle/lepton is fundamental particle
or
hadron made of quarks/lepton not made of quarks
or
strong force/interaction acts on hadrons/does not act on leptons B1 [1]

(b) **(i)** ${}^{0}_{1}e^{(+)}$ or ${}^{0}_{1}\beta^{(+)}$ B1

${}^{0}_{0}\nu_{(e)}$ B1 [2]

(ii) weak (nuclear force / interaction) B1 [1]

(iii)
- mass-energy
- momentum
- proton number
- nucleon number
- charge

Any three of the above quantities, 1 mark each B3 [3]

(c) (quark structure of proton is) up, up, down or uud B1

up/u (quark charge) is (+)⅔(*e*), down/d (quark charge) is –⅓(*e*) C1

$\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e = (+)e$ A1 [3]

Q27 **a)** hadron not a fundamental particle/lepton is fundamental particle
or
hadron made of quarks/lepton not made of quarks
or
strong force/interaction acts on hadrons/does not act on leptons — B1 [1]

(b) **(i)** proton: up, up, down / uud — B1
neutron: up, down, down / udd — B1 [2]

(ii) composition: 2(uud) + 2(udd)
= 6 up, 6 down / 6u, 6d — B1 [1]

(c) **(i)** most of the atom is empty space
or
the nucleus (volume) is (very) small compared to the atom — B1 [1]

(ii) nucleus is (positively) charged — B1

the mass is concentrated in (very small) nucleus/small region/small volume/small core
or
the majority of mass in (very small) nucleus/small region/small volume/small core — B1 [2]

Q28 **(a)** both electron and neutrino: lepton(s) — B1

both neutron and proton: hadron(s)/baryon(s) — B1 [2]

(b) **(i)** $^{1}_{1}p \rightarrow ^{1}_{0}n + ^{0}_{1}\beta + ^{0}_{0}\nu$

correct symbols for particles — M1

correct numerical values (allow no values on neutrino) — A1 [2]

(ii) up up down or uud $\rightarrow$ up down down or udd — B1 [1]

(iii) weak (nuclear) — B1 [1]

Q29	(quark structure is) up, down, down/udd	**B1**
	up/u has charge +⅔(*e*), down/d has charge –⅓(*e*)	**C1**
	+⅔*e* –⅓*e* –⅓*e* = 0	**A1**
8(b)	charge: p $+1.6(0) \times 10^{-19}$ (C) **or** $+e$ β^- $-1.6(0) \times 10^{-19}$ (C) **or** $-e$ $\bar{\nu}$ zero/0	**B1**
	mass: p 1.67×10^{-27} (kg)/1.7×10^{-27} (kg) β^- $9.1(1) \times 10^{-31}$ (kg) $\bar{\nu}$ very small/zero/0	**B1**

Q30	–1 / decreases by 1	**A1**
6(b)	$I = Q / t$ or Ne / t	**C1**
	$= (9.8 \times 10^{10} \times 1.6 \times 10^{-19}) / (2.0 \times 60)$ $= 1.3 \times 10^{-10}$ (A)	**C1**
	= 130 pA	**A1**
6(c)	antineutrino(s) (emitted) / other particle(s) (emitted)	**C1**
	energy / momentum shared with antineutrino(s)	**A1**